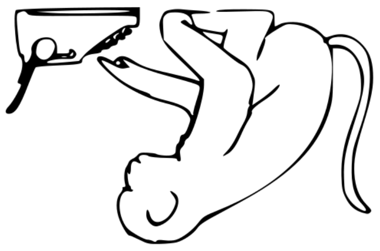
IMITATOR User Manual



Version 2.7.1 (Butter Guéméné)

Build 1245
July 27, 2015

www.imitator.fr

Contents

Chapter 1

Introduction

IMITATOR is an open source software tool to perform automated parameter synthesis for concurrent timed systems [AFKS12]. IMITATOR takes as input a network of IMITATOR parametric timed automata (NIPTA): NIPTA are an extension of parametric timed automata [AHV93], a well-known formalism to specify and verify models of systems where timing constants can be replaced with parameters, *i.e.*, unknown constants.

IMITATOR addresses several variants of the following problem: "given a concurrent timed system, what are the values of the timing constants that guarantee that the model of the system satisfies some property?" Specifically, IMITATOR implements parametric safety analysis [AHV93, JLR15], the inverse method [ACEF09, AM15], the behavioral cartography [AF10], and parametric reachability preservation [ALNS15]. Some algorithms can also run distributed on a cluster. Numerous analysis options are available.

IMITATOR is a command-line only tool, but that can output results in graphical form. Furthermore, a graphical user interface is available in the *CosyVerif* platform [AHHH$^+$13].

IMITATOR was able to verify numerous case studies from the literature and from the industry, such as communication protocols, hardware asynchronous circuits, schedulability problems and various other systems such as coffee machines (probably the most critical systems from a researcher point of view). Numerous benchmarks are available at IMITATOR Web page [IMI15].

In this document, we present the input syntax, we formally define the input model of IMITATOR, and we explain how to perform various analyses using the numerous options.

Keywords: formal verification, model checking, software verification, parameter synthesis

Chapter 2

A Brief Introduction to the Syntax

We first briefly introduce the syntax using a simple example for readers familiar with parametric timed automata, and not interested in subtle details (such as the synchronization model). A formal (and nearly exhaustive) definition of IMITATOR parametric timed automata (NIPTA) can be found in Chapter 3. The complete syntax is given in Chapter 8.

Generalities IMITATOR performs parametric verification of models specified using networks of IMITATOR parametric timed automata (hereafter NIPTA). An IMITATOR parametric timed automaton (hereafter IPTA) is a variant of parametric automata (as introduced in [AHV93]). IPTA and NIPTA are formalized in Section 3.1.

The input syntax of IMITATOR is originally based on the syntax of HyTech [HHWT95], with several improvements. Actually, all standard HyTech files describing only PTA (and not more general systems like linear hybrid automata [ACHH93]) can be analyzed directly by IMITATOR (sometimes with very minor changes).

Comments are OCaml-like comments starting with `(*` and ending with `*)`. As in OCaml, comments can be nested.

The Fischer mutual exclusion protocol We use as a motivating example one timed version of the Fischer mutual exclusion protocol, coming from the PAT model checker [SLDP09]. This version of the protocol is neither the most complete, nor the most simple; we just use it here to introduce various aspects of the IMITATOR input syntax.

Fischer mutual exclusion protocol is a protocol that guarantees the mutual exclusion of several processes (here two) that want to access a shared resource (called the critical section).

Input syntax We give below this model using the IMITATOR syntax. Note that this model is given in graphical form in Fig. 2.1.[1]

```
(************************************************************
 *                    IMITATOR MODEL
 *
 * Fischer's mutual exclusion protocol
 *
 * Description     : Fischer's mutual exclusion protocol with 2 processes
 * Correctness     : Not 2 processes together in the critical section
     (location obs_violation unreachable)
 * Source          : PAT library of benchmarks
 * Author          : ?
 * Input by        : Etienne Andre
 *
 * Created         : 2012/10/08
 * Last modified   : 2015/07/20
 *
 * IMITATOR version: 2.7-beta4
 ************************************************************)

var
    x1, (* proc1's clock *)
    x2, (* proc2's clock *)
        :clock;

    turn,
    counter
        : discrete;

    delta,
    gamma
        : parameter;

    IDLE = -1
        : constant;

(************************************************************)
automaton proc1
(************************************************************)
synclabs: access_1, enter_1, exit_1, no_access_1, try_1, update_1;

loc idle1: while True wait {}
    when turn = IDLE sync try_1 do {x1' = 0} goto active1;

loc active1: while x1 <= delta wait {}
    when True sync update_1 do {turn' = 1, x1' = 0} goto check1;

loc check1: while True wait {}
    when x1 >= gamma & turn = 1 sync access_1 do {x1' = 0} goto access1;
```

[1] This LaTeX representation, that makes use of the LaTeX TikZ library, was automatically output by IMITATOR, using option -PTA2TikZ, followed by some manual positioning optimization.

```
    (* No "<>" operator: hence we use both '>' and '<' *)
    when x1 >= gamma & turn < 1 sync no_access_1 do {x1' = 0}  goto idle1;
    when x1 >= gamma & turn > 1 sync no_access_1 do {x1' = 0}  goto idle1;

loc access1: while True wait {}
    when True sync enter_1 do {counter' = counter + 1} goto CS1;

loc CS1: while True wait {}
    when True sync exit_1 do {counter' = counter - 1, turn' = IDLE, x1' =
        0} goto idle1;

end (* proc1 *)


(************************************************************)
automaton proc2
(************************************************************)
synclabs: access_2, enter_2, exit_2, no_access_2, try_2, update_2;

loc idle2: while True wait {}
    when turn = IDLE sync try_2 do {x2' = 0} goto active2;

loc active2: while x2 <= delta wait {}
    when True sync update_2 do {turn' = 2, x2' = 0} goto check2;

loc check2: while True wait {}
    when x2 >= gamma & turn = 2 sync access_2 do {x2' = 0} goto access2;
    (* No "<>" operator: hence we use both '>' and '<' *)
    when x2 >= gamma & turn < 2 sync no_access_2 do {x2' = 0} goto idle2;
    when x2 >= gamma & turn > 2 sync no_access_2 do {x2' = 0} goto idle2;

loc access2: while True wait {}
    when True sync enter_2 do {counter' = counter + 1} goto CS2;

loc CS2: while True wait {}
    when True sync exit_2 do {counter' = counter - 1, turn' = IDLE, x2' =
        0} goto idle2;

end (* proc2 *)


(************************************************************)
automaton observer
(************************************************************)
synclabs : enter_1, enter_2, exit_1, exit_2;

loc obs_waiting: while True wait {}
    when True sync enter_1 goto obs_1;
    when True sync enter_2 goto obs_2;

loc obs_1: while True wait {}
    when True sync exit_1 goto obs_waiting;
    when True sync enter_2 goto obs_violation;

```

```
loc obs_2: while True wait {}
    when True sync exit_2 goto obs_waiting;
    when True sync enter_1 goto obs_violation;

(* NOTE: no outgoing action to reduce state space *)
loc obs_violation: while True wait {}

end (* observer *)


(************************************************************)
(* Initial state *)
(************************************************************)
init :=
    (*------------------------------------------------------------
      INITIAL LOCATION
    ------------------------------------------------------------*)
    & loc[proc1] = idle1
    & loc[proc2] = idle2
    & loc[observer] = obs_waiting

    (*------------------------------------------------------------
      INITIAL CLOCKS
    ------------------------------------------------------------*)
    & x1 >= 0
    & x2 >= 0

    (*------------------------------------------------------------
      INITIAL DISCRETE
    ------------------------------------------------------------*)
    & turn = IDLE
    & counter = 0

    (*------------------------------------------------------------
      PARAMETER CONSTRAINTS
    ------------------------------------------------------------*)
    & delta >= 0
    & gamma >= 0
;

(************************************************************)
(* Property specification *)
(************************************************************)
property := unreachable loc[observer] = obs_violation;

(************************************************************)
(* The end *)
(************************************************************)
end
```

Header Let us comment this case model by starting with the header. First, text in comments gives generalities about the model (author, date, description, etc.).

The form is not normalized, but it could be in the future, so it is strongly advised to follow this form.[2]

Variable declarations The variable declarations starts with keyword `var`.

This model contains two clocks: `x1` is process 1's clock, and `x2` is process 2's clock.

This model contains two parameters: `delta` is the parametric duration specifying how long a process is idle at most, whereas `gamma` is the parametric duration specifying the minimum duration between the time a process checks for the availability of the critical section and the time the same process indeed enters the critical section (if it is still available).

Two discrete variables (*i.e.*, global, integer-valued variables, see Section 3.2) are used: `turn` checks which process is attempting to enter the critical section; `counter` records how many processes are in the critical section (this variable will not be used for the verification, but was used in the original PAT model, and we choose to keep it).

Finally, a global constant `IDLE` is set to `-1` (just as in the original PAT model), and encodes that no process is attempting to enter the critical section.

Automata This model contains three IPTA: the first and second ones (`proc1` and `proc2`) model the first and second process, respectively. The third one (`observer`) is an observer, *i.e.*, an IPTA that checks the system behavior without modifying it.

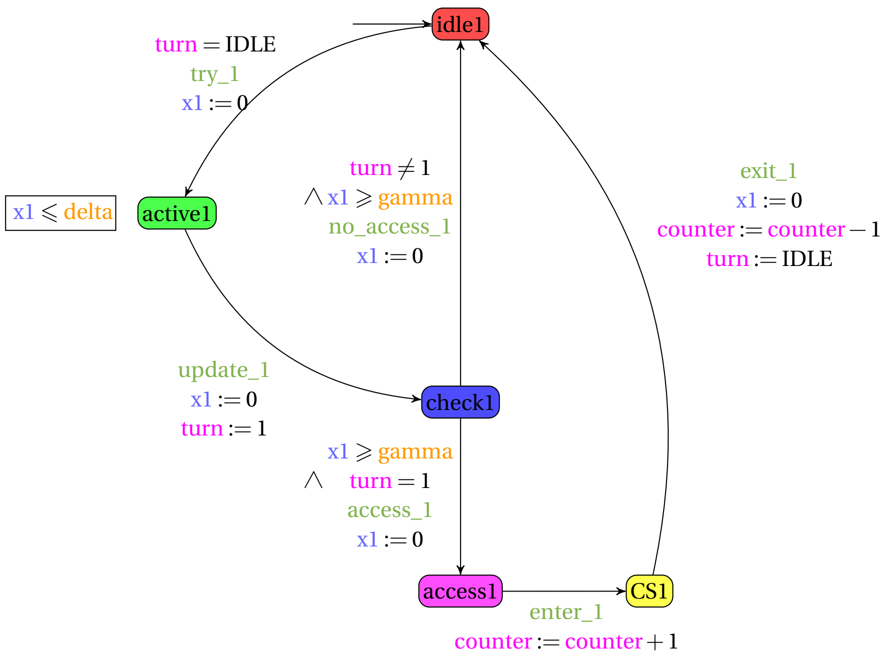
The first process Let us first describe the IPTA `proc1` (a graphical representation is given in Fig. 2.1a). This IPTA uses six actions, given in the `synclabs` declaration.

`proc1` is initially in location `idle1`, with no invariant (depicted by `while True wait {}`). At any time, when the discrete variable `turn` is equal to `IDLE`, then this IPTA may synchronize on action `try_1`, reset its clock `x1`, and enter location `active1`.

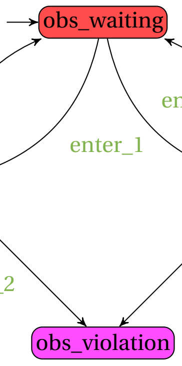
The invariant of this location is `x1 <= delta`, *i.e.*, `proc1` can only remain in `active1` as long as the value of `x1` does not exceed `delta`. At any time, this IPTA may synchronize on action `update_1`, reset its clock `x1` and set the global variable `turn` to `1`, and enter location `check1`.

In location `check1`, the process wait at least `gamma` time units (modeled by the inequality `x1 >= gamma`, in all outgoing transitions). If `turn` is still equal to `1` (that is, no other process attempted in the meanwhile to enter the critical section), then process 1 is indeed ready to enter the critical section, by synchronizing `access_1` and resetting `x1`. If `turn` is different from `1` (that is, another

[2]An empty model template with all these comments ready to be filled out (containing also a sample IPTA and its initial definitions) is available at:
https://github.com/etienneandre/imitator/blob/master/examples/model.imi.



(a) Process 1



(b) PTA observer

Figure 2.1: Fischer mutual exclusion protocol

process attempted in the meanwhile to enter the critical section, and it is not safe for process 1 to enter), then process 1 returns to its idle location, by synchronizing `no_access_1` and resetting `x1`. Note that we have to use two transitions checking that either `turn < 1` or `turn > 1` to compensate that the "different from" operator ("$\neq$") is not (yet) supported by IMITATOR.

In location `access1`, process 1 can remain any time, and eventually enters the critical section by synchronizing `enter_1` and incrementing the global variable `counter` by 1.

In location `CS1`, process 1 can remain any time, and eventually leaves it, by decrementing the global variable `counter` by 1, and setting the global variable `turn` to its initial value `IDLE`.

The second process Process 2 is identical to process 1, except that `x1` is replaced with `x2`, and that the value of `turn` becomes 2.

The observer The observer is in charge to check that no more than one process is in critical section at the same time.[3] This observer will detect that this situation happens if an action `enter_1` is followed by an action `enter_2` without an action `exit_1` in between (or symmetrically if an action `enter_2` is followed by an action `enter_1` without an action `exit_2` in between). Note that the observer simply observes the system state, and synchronizes on the actions used by `proc1` and `proc2`; it does not use any clock nor variable.

A graphical representation of the IPTA `observer` is given in Fig. 2.1b.

Initial definitions The initial state is defined the part of the file following `init :=`. This part must contain the initial location of each IPTA. For example, `loc[proc1] = idle1` states that `proc1` is initially in location `idle1`.

The initial definition may (only may, see Section 3.3) give an initial value to the clocks, for example requiring them to be equal to some constant (typically 0). Here, clocks are only bound to be greater or equal to 0.

The initial definition should assign a constant value to each discrete variable: here `turn` is initially equal to `IDLE`, and `counter` is initially equal to 0.

Finally, parameters are bound to be positive or null (this is not assumed by default by IMITATOR, so users are strongly advised to add this constraint).

Note that the initial definition can introduce more complex constraints on clocks, parameters and discrete variables; see Section 3.3 for details.

[3]This observer is not really necessary to check the correctness of this protocol; instead of adding this observer and checking `unreachable loc[observer] = obs_violation`, one could just check either `counter > 1` or `loc[proc1] = CS1 & loc[proc2] = CS2`. However, IMITATOR does not (yet) support checking global variables or more that one location in the `unreachable` property (which should be fixed very soon!); furthermore, introducing an observer is also useful, as it is often used for verification.

Property specification In this model, the correctness property is that two processes cannot be in the critical section at the same time; as explained above, this is equivalent to the fact that the `obs_violation` location of the `observer` IPTA is unreachable. This is input in the model as follows:

```
property := unreachable loc[observer] = obs_violation;
```

More elaborate properties are detailed in Section 4.3 (however, they all *reduce* to reachability, so more complex properties such as Büchi-like properties or fairness are not yet supported by IMITATOR).

Parameter synthesis Finally, let us run IMITATOR on this case study. Quite naturally, what we would be interested in is knowing for which parameter valuations this protocol is correct, *i.e.*, no more than one process can be present in the critical section at one time. Assuming this model is input in file `fischer.imi`, the command calling IMITATOR is as follows:

```
$ ./imitator fischer.imi -mode EF -merge
```

In this command, `-mode EF` calls the algorithm EFsynth that synthesizes valuations reaching a given location (see Section 4.2); and `-merge` is a merging technique reducing the state space that, for this model, ensures termination (see [AFS13] for more details on merging).

The result of the call to IMITATOR is

```
 Final constraint such that the property is *violated* (1
constraint):
delta >= gamma
& gamma >= 0
```

That is, the system is safe if `delta < gamma`, which is the well-known constraint ensuring mutual exclusion for this protocol.

Chapter 3

IMITATOR Parametric Timed Automata

3.1 Formal Definition

IMITATOR performs parametric verification of models specified using networks of IMITATOR parametric timed automata (hereafter NIPTA).

An IMITATOR parametric timed automaton (hereafter IPTA) is a variant of parametric automata (as introduced in [AHV93]). A first difference between IPTA and the PTA of [AHV93] is that IPTA have no accepting / final location; furthermore, IPTA augment the expressiveness of PTA with several features such as invariants, discrete (integer) variables, complex guards and invariants (*i.e.*, not only comparing a single clock to a single parameter), stopwatches (*i.e.*, the ability to stop some clocks in some locations), and arbitrary clock updates (*i.e.*, not necessarily to 0).

3.1.1 Linear Constraints

Clocks, Parameters, Discrete Variables *Clocks* are real-valued variables all evolving at the same rate (unless they are stopped, which is allowed in IMITATOR). A set of clocks is $X = \{x_1, \dots, x_H\}$; a clock valuation is $w \colon X \to \mathbb{R}_{\geqslant 0}$.

Parameters are rational-valued variables, that act as unknown constants. A set of parameters is $P = \{p_1, \dots, p_M\}$; a parameter valuation is a function $v \colon P \to \mathbb{R}$. We will often identify a valuation v with the *point* $(v(p_1), \dots, v(p_M))$.

Discrete variables are integer-valued variables. A set of discrete variables is $D = \{d_1, \dots, d_J\}$; a discrete variable valuation is a function $\delta \colon D \to \mathbb{N}$.

Linear Constraints Let us formalize the set of linear constraints allowed in IMITATOR. Given a set of variables $Var = \{z_1, \dots, z_N\}$ (in the following, this set will be instantiated with X and/or P and/or D), a *linear term* over *Var* is an expression of the form

$$\sum_{1 \leqslant i \leqslant n} \alpha_i z_i + d$$

for some $n \in \mathbb{N}$, where $z_i \in \mathit{Var}$, $\alpha_i \in \mathbb{Q}$, for $1 \leqslant i \leqslant n$, and $d \in \mathbb{Q}$.

An *atomic constraint* over *Var* is an expression of the form $\mathit{lt} \prec 0$ where *lt* is a linear term over *Var*, and $\prec \in \{, \leqslant, \geqslant, \}$.

A *constraint* over *Var* is a conjunction of atomic constraints. We denote by $\mathscr{LT}(\mathit{Var})$ the set of linear terms over *Var*, and by $\mathscr{LC}(\mathit{Var})$ the set of constraints over *Var*. In IMITATOR, we will consider constraints belonging to sets such as $\mathscr{LC}(X \cup P)$ (*i.e.*, the set of constraints over clocks and parameters), or $\mathscr{LC}(X \cup P \cup D)$ (*i.e.*, the set of constraints over clocks, parameters and discrete variables).

3.1.2 IMITATOR Parametric Timed Automata

We can now give a formal definition of IPTA.

Let ϵ denote the unobservable action.

Definition 1 (IPTA)**.** *An IMITATOR parametric timed automaton (*IPTA*) is a tuple* $\mathscr{A} = \langle \Sigma, L, l_{\mathit{init}}, D, X, P, I, S, \rightarrow \rangle$*, where:*

- Σ *is a finite set of actions;*
- L *is a finite set of locations;*
- $l_{\mathit{init}} \in L$ *is the initial location;*
- D *is a set of integer-valued variables;*
- X *is a set of clocks;*
- P *is a set of parameters;*
- $I : L \rightarrow \mathscr{LC}(X \cup P \cup D)$ *assigns to every location* l *a constraint over all variables, called the* invariant *of* l*;*
- $S : L \rightarrow X$ *assigns to a every location a list of clocks that are stopped in this location;*
- $\rightarrow$ *is a set of edges* $(l, g, a, X_{\mathsf{up}}, D_{\mathsf{up}}, l')$*, where* $l, l' \in L$ *are the source and destination locations,* $g \in \mathscr{LC}(X \cup P \cup D)$ *is a constraint over all variables (called* guard *of the transition),* $a \in \Sigma \cup \{\epsilon\}$ *is the action associated with the transition,* $X_{\mathsf{up}} : X \rightarrow \mathscr{LT}(X \cup P \cup D)$ *is the update function for clocks, and* $D_{\mathsf{up}} : D \rightarrow \mathscr{LT}(D)$ *is the update function for discrete variables.*

In the following, we explain this definition.

Guards and invariants Guards and invariants in IMITATOR are linear constraints over all variables. For example, the following expression can be used in a guard or an invariant:

```
i1 + .5 x1 + 3 x2 >= 2 p1 - i2 & p2 < 1/3
```

where `i1`, `i2` are discrete variables, `x1`, `x2` are clocks and `p1`, `p2` are parameters. This syntax includes in particular diagonal constraints (*e.g.*, `x1 - x2 <= 2`), not always supported in other model-checking tools.

Actions Transitions can be synchronized on an action in Σ, or have no synchronized action ("ϵ"), which is often referred to in the literature as a silent transition, or an ϵ-transition. For the semantics of the synchronization model between various IPTA, refer to Section 3.4.

Clock updates Observe that clocks can be updated to any value, *i.e.*, a clock can be assigned not only to 0, but to any linear term over the other clocks, the parameters and the discrete variables. However, discrete variables can only be assigned to a linear term over D (including a constant). If clocks are always reset (*i.e.*, not assigned to more complex linear terms), IMITATOR will apply some optimizations that (may) increase the analysis speed.

Stopwatches There are no distinction between clocks and stopwatches. That is, any clock can potentially be stopped in some location. IMITATOR will detect whether a model has or not stopwatches; if there is no stopwatch in some model, IMITATOR will apply some optimizations that (may) increase the analysis speed.

3.1.3 Networks of IMITATOR Parametric Timed Automata

Definition 2 (NIPTA)**.** *Given a set of IPTA* $\mathscr{A}_i = \langle \Sigma_i, L_i, (l_{init})_i, D_i, X_i, P_i, I_i, S_i, \rightarrow_i \rangle$, $1 \leqslant i \leqslant N$ *for some* $N \in \mathbb{N}$, *a network of IPTA (*NIPTA*) is a tuple* $\langle \Sigma, D, X, P, \{\mathscr{A}_i \mid 1 \leqslant i \leqslant N\}, C_{init} \rangle$, *where:*

- $\Sigma = \bigcup_{1 \leqslant i \leqslant N} \Sigma_i$ *is the set of all actions;*
- $D = \bigcup_{1 \leqslant i \leqslant N} D_i$ *is the set of all discrete variables;*
- $X = \bigcup_{1 \leqslant i \leqslant N} X_i$ *is the set of all clocks;*
- $P = \bigcup_{1 \leqslant i \leqslant N} P_i$ *is the set of all parameters;*
- $C_{init} \in \mathscr{LC}(X \cup P \cup D)$ *is the initial constraint over* D, X *and* P.

Observe that each set of actions, discrete variables, clocks and parameters is not disjoint between all IPTA. That is, actions, discrete variables, clocks and parameters may be shared between different IPTA. If a variable is required to be local to an IPTA, then it should just not be used in any other IPTA of the model.

Different from many tools for (parametric) timed automata, clocks are not necessarily initially equal to 0 (this is similar to HyTech [HHWT95] but different from Uppaal [LPY97]). The initial value of the clocks is defined by C_{init} (see Section 3.3). If nothing is defined in C_{init}, then their value is supposed to be arbitrary (any real value greater or equal to 0).

Note that parameters are not assumed positive; however, the behavior of IMITATOR has not been tested for negative parameters, and it is strongly advised to constrain them to be positive in C_{init} (if it is not the case, a warning is issued by IMITATOR).

Finally, note that the number of IPTA, locations, variables and actions that can be defined in a model is bounded in IMITATOR by some very large number (most probably 2^{32}); but, well, you don't seriously plan to build such a large model, do you?

3.2 Discrete Variables

Discrete variables[1] are global integer-valued variables. Their value is global, in the sense that they are shared by all IPTA of the model. They can be seen as syntactic sugar to represent a possibly unbounded number of locations.

In IMITATOR, integers are exact and unbounded, just as in maths (*i.e.*,, they are *not* represented using a limited number of bits, such as 32 or 64 bits). Hence, no overflow can occur, and the representation of the constraints is always exact. Note that floating-point numbers are totally absent from the IMITATOR implementation (except for th generation of graphical outputs).

Discrete variables must be initialized to a single constant value in the `init` definition; if they are not, a warning is issued, and they are arbitrarily set to 0.

Discrete variables can be tested in guards, and updated along transitions. They are first tested, then updated. If two IPTA in parallel update the same variable on the same synchronized transition (*e.g.*, an IPTA performs `i' = 2` while another one performs `i' = 3`), then a warning is issued, and the behavior of the NIPTA becomes unspecified (*i.e.*, IMITATOR will choose one or the other assignment in a non-deterministic manner).

3.3 Initial State and Initialization of Variables

For each IPTA, a unique initial location must be defined.

[1]The name "discrete variable" comes from HyTech.

For variables, the definition of the initial value is very permissive in IMITATOR. Clocks are not necessarily equal to 0, and parameters are not even necessarily positive.

Parameters and clocks can be initially bound by any linear constraint over parameters, clocks, and discrete variables. That is, we can define initial constraints such as:

```
x1 + x2 <= 2 p1 + 0.5 p2 - i.
```

However, discrete variables must be initialized to a *constant integer*. Given a discrete variable `i`, if the definition of the initial state does not contain an equality of the form `i = ...` followed by a linear term in $\mathscr{LT}(\mathsf{X} \cup \mathsf{P} \cup \mathsf{D})$, then IMITATOR will assume that `i` is initially set to 0, and will issue a warning.

3.4 Synchronization Model

By default, all IPTA of an IMITATOR model declare their set of actions.[2]

The IMITATOR synchronization model is such that *all* IPTA declaring an action must synchronize *together* on this action. This can be seen as a *strong broadcast*. That is, for a transition labeled with action `a` to be executed, all IPTA declaring `a` must be ready to execute `a` locally. Otherwise, this transition cannot be taken (yet).

If an IPTA declares an action `a` that is never used in this IPTA, then action `a` will never be executed in the entire model.[3]

3.5 Constants

IMITATOR supports global constants, *i.e.*, a variable the value of which is known once for all. The syntax is the following one:

```
c = 1: constant;
```

Then, any occurrence of `c` in the model is replaced with `1`.

Constants are (unbounded, exact) integers.

Hint 1. *In fact, a variable (e.g., a parameter) can be turned to a constant as follows in the definition of the parameters:*

```
p = 2: parameter;
```

[2]An alternative is an automatic recognition of the actions used, see option `-sync-auto-detect` in Chapter 7.

[3]In this case, IMITATOR will detect this situation and will entirely delete this action from the model, while issuing a warning.

This is equivalent to replacing `p` *with* `2` *everywhere in the model; this is particularly useful when some parameters should be instantiated. In contrast, if the parameter is instantiated in the initial definition,* IMITATOR *still counts it as a parameter, which makes all constraints suffer from an additional dimension.*

Chapter 4

Parameter Synthesis Using IMITATOR

We give here the commands corresponding to the main analysis features of IMITATOR. We only give the most useful options. For more detailed commands, and a complete list of options, see Chapter 7.

4.1 State Space Computation

IMITATOR can compute the entire symbolic state space ("parametric zone graph"). Of course, the state space may be infinite, and this analysis is not guaranteed to terminate.

The standard command is:

```
$ ./imitator model.imi -mode statespace -output-states
```

The option `-output-states` generates a file with a textual description of all states (without this option, IMITATOR will not output anything).

IMITATOR can also output the trace set in a graphical form using option `-output-trace-set`.

4.2 EF-Synthesis

A main problem in parametric timed automata is to compute the set of parameter valuations for which some location (for instance, an error location) is reachable.

The property must be specified as follows, at the end of the model (after the initial state definition):

```
property := unreachable loc[AUTOMATON] = LOCATION
```

where `AUTOMATON` is an automaton name, and `LOCATION` is a location name.

The algorithm EFsynth implemented in IMITATOR is a basic breadth-first procedure, close to the one described in [AHV93, JLR15]. Of course, the EF-emptiness problem being undecidable [AHV93], the analysis is not guaranteed to terminate.

The standard command is:

```
$ ./imitator model.imi -mode EFsynth -merge -incl
```

The options `-merge` and `-incl` are optional, but generally greatly increase the analysis efficiency and the termination. The option `-dynamic-elimination` can also be used to reduce the state space.

IMITATOR can also output the trace set in a graphical form (option `-output-trace-set`), output the constraint synthesized in a graphical form in two dimensions (option `-output-cart`), or output the result to a text file (option `-output-result`).

4.3 Parametric Verification using Properties

IMITATOR basically only supports bad state reachability synthesis on the one hand, and algorithms such as the inverse method and the cartography on the other hand. However, many correctness properties can be encoded using reachability using *observers* (see [ABL98, ABBL98, And13b]).

Encoding observers can be done manually (using *ad-hoc* IPTA), or using predefined correctness properties commonly met in the literature.

If using a predefined property, the property must be specified as follows, at the end of the model (after the initial state definition):

`property := [PROP]`

`[PROP]` must conform to one of the following patterns, where `AUTOMATON` is an automaton name, `LOCATION` is a location name, `a`, `a1`, `a2` are actions, and the deadline `d` is a (possibly parametric) linear expression:

- `property := unreachable loc[AUTOMATON] = LOCATION`
- `property := if a2 then a1 has happened before`
- `property := everytime a2 then a1 has happened before`
- `property := everytime a2 then a1 has happened once before`
- `property := a within d`
- `property := if a2 then a1 has happened within d before`
- `property := everytime a2 then a1 has happened within d before`
- `property := everytime a2 then a1 has happened once within d before`

- `property := if a1 then eventually a2 within d`
- `property := everytime a1 then eventually a2 within d`
- `property := if a1 then eventually a2 within d once before next`
- `property := sequence a1, ..., an`
- `property := always sequence a1, ..., an`

The semantics of these properties is detailed in [And13b].

Then, the command to synthesize parameters is the same as for the EF-synthesis:

```
$ ./imitator model.imi -mode EFsynth -merge -incl
```

4.4 Inverse Method: Trace Preservation

Given a NIPTA and a reference parameter valuation, the inverse method IM synthesizes a parameter constraint such that, for any parameter valuation in that constraint, the set of traces is the same as for the reference valuation [ACEF09]. This problem is known as the trace preservation synthesis. The trace-preservation emptiness problem being undecidable [AM15], the analysis is not guaranteed to terminate (although it often does in practice).

The command is:

```
$ ./imitator model.imi model.pi0
```

The reference valuation is described in `model.pi0`.

IMITATOR can also output the trace set in a graphical form (option `-output-trace-set`), or output the result to a text file (option `-output-result`).

4.5 Behavioral Cartography

Given a NIPTA and a bounded parameter domain, the behavioral cartography BC synthesizes tiles, *i.e.*, parameter domains such that for any parameter valuation in that domain, the set of traces is the same [AF10]. The corresponding problem being undecidable, the analysis is not guaranteed to terminate; when it terminates, it may also leave "holes", *i.e.*, parameter domains not covered by any tile.

The command is:

```
$ ./imitator model.imi model.v0 -mode cover
```

The bounded parameter domain is described in `model.v0`.

IMITATOR can also output all trace sets in a graphical form (option `-output-trace-set`), output the constraints synthesized in a graphical form in two dimensions (option `-output-cart`), or output the result to a text file (option `-output-result`).

The option `-step` specifies the interval between any two points of which the coverage is checked (see [AF10]). By default, it is 1; setting $\frac{1}{3}$ often leads to full coverage when 1 was not enough.

Behavioral Cartography with Random Coverage

An alternative to the behavioral cartography is a random coverage; it can be seen as a kind of sampling.

The command is:

```
$ ./imitator model.imi model.v0 -mode randomXX
```

where `XX` is the number of times an integer point is randomly selected within the domain defined in `model.v0`. If this point is already covered by one of the tiles, the inverse method is not called, an another point is selected. Note that `XX` represents the number of integer points randomly selected; the number of calls to the inverse method can be significantly smaller.

4.6 Parametric Reachability Preservation

IMITATOR implements an algorithm solving the following problem: "given a reference parameter valuation v and some location l, synthesize other valuations that preserve the reachability of l". By preserving the reachability, we mean that l is reachable for the other valuations iff l is reachable for v.

This algorithm PRP, that combines EFsynth and IM (see [ALNS15] for details), is called as follows:

```
$ ./imitator model.imi model.pi0 -PRP
```

Note that a bad location (as in Section 4.2) or a property (as in Section 4.3) must be defined in the model.

Parametric Reachability Preservation Cartography

An extension of PRP to the cartography (named PRPC) is also available: PRPC synthesizes parameter constraints in which the (non-)reachability of l is uniform. PRPC was showed in [ALNS15] to be a good alternative to EFsynth, especially when distributed.

This algorithm PRPC is called as follows:

```
$ ./imitator model.imi model.v0 -mode cover -PRP
```

Again, a bad location (as in Section 4.2) or a property (as in Section 4.3) must be defined in the model.

Chapter 5

Graphical Output and Translation

Again, we only give the most useful options. For more detailed commands, and a complete list of options, see Chapter 7.

5.1 Trace Set

To generate the trace set of a given computation in a graphical form, use:

```
$ ./imitator model.imi [options] -output-trace-set
```

IMITATOR will generate a file `model.jpg`. Note that, beyond about 1,000 states or 1,000 transitions, the `dot` utility (responsible to generate the trace set) may crash.

Using `-output-trace-set-nodetails` makes a more compact representation (but is also less informative).

5.2 Constraints and Cartography

To generate the constraint generated by IMITATOR in a 2-dimensional plot (using the plot utility), use:

```
$ ./imitator model.imi [options] -output-cart
```

This will generate file `model_cart_ef.png` if the algorithm is EFsynth, `model_cart_bc.png` if the algorithm is BC and its variant, or `model_cart_patator.png` if the algorithm is the distributed BC and its variants.

The 2 dimensions chosen for the plot are the first two (non-constant) parameter dimension in the model.

Additional useful options are `-output-cart-x-min`, `-output-cart-x-max`, `-output-cart-y-min`, `-output-cart-y-max` to tune the values of the axes, and `-output-graphics-source` to keep the plot source.

The graphical output of the constraint is not yet available for the inverse method.

5.3 Export to JPEG

To generate a graphic representation of the model without performing any analysis, use:

```
$ ./imitator model.imi -PTA2JPG
```

IMITATOR will generate a file `model-pta.jpg`.

5.4 Export to LaTeX

To generate a LaTeX representation of the model (using the `tikz` package) without performing any analysis, use:

```
$ ./imitator model.imi -PTA2TikZ
```

IMITATOR will generate a file `model.tex`. This file is a standalone LaTeX file containing a single figure, which contains the different IPTA in `subfigure` environments. The node positioning is not yet supported (locations are depicted vertically), so you may need to manually position all nodes, and bend some transitions if needed.

Chapter 6

Inside the Box

6.1 Language and Libraries

In short, IMITATOR is written in OCaml, and contains about 26,000 lines of code.

IMITATOR makes use of the following external libraries:

- The OCaml ExtLib library (Extended Standard Library for Objective Caml);
- The GNU Multiple Precision Arithmetic Library (GMP);
- The Parma Polyhedra Library (PPL) [BHZ08], used to compute operations on polyhedra.

6.2 Symbolic States

Verification of timed systems (and specially parametric timed systems) is necessarily done in a symbolic manner, in the sense that the timing information is abstracted by clock constraints. However, IMITATOR does not perform what is referred to as *symbolic model checking*; in other words, the representation of locations in IMITATOR is explicit (and not symbolic using, *e.g.*, binary decision diagrams).

In short, a symbolic state in IMITATOR is made of the following elements:

- the current location (index) of each IPTA;
- the current value of the (integer-valued) discrete variables;
- a constraint on $X \cup P \cup D$ representing the continuous information.

In IMITATOR, all integers (*i.e.*, the value of the discrete variables and the coefficients used in the constraints) are unbounded integers (implemented using GMP).

6.3 Installation

This document does not aim at explaining how to install IMITATOR. See the installation information available on the website for the most up-to-date information.

Binaries and source code packages are available on IMITATOR's Web page [IMI15]. Several standalone binaries are provided for Linux systems, that require no installation.

Chapter 7

List of Options

The options available for IMITATOR are explained in the following.

Note that some more options are available in the current implementation of IMITATOR. If these options are not listed here, they are experimental (or deprecated). If needed, more information can be obtained by contacting the IMITATOR team.

`-acyclic` **(default: false)** Does not test if a new state was already encountered. Without this option, when IMITATOR encounters a new state, it checks if it has been encountered before. This test may be time consuming for systems with a high number of reachable states. For acyclic systems, all traces pass only once by a given location. As a consequence, there are no cycles, so there should be no need to check if a given state has been encountered before. This is the main purpose of this option.

However, be aware that, even for acyclic systems, several (different) traces can pass by the same state. In such a case, if the `-acyclic` option is activated, IMITATOR will compute *twice* the states after the state common to the two traces. As a consequence, it is all but sure that activating this option will lead to an increase of speed.

Note also that activating this option for non-acyclic systems may lead to an infinite loop in IMITATOR.

`-check-ippta` **(default: false)** Check that every new symbolic state contains an integer point (*i.e.*, a point in the $X \cup P$ dimension). If not, raises an exception.

`-check-point` **(default: false)** In the inverse method, checks at each iteration whether the accumulated parameter constraint is restricted to the reference parameter valuation. Note that this option is not implemented as nicely as it could be, and can hence turn very costly.

`-completeIM` **(default: false)** Returns a complete result for the inverse method for deterministic PTA, *i.e.*, returns a conjunction of negations of convex parameter constraints. The result may result in a large list of such constraints, and may hence be complicated to interpret.

`-contributors` Print the list of contributors and exits.

`-depth-limit <limit>` **(default: none)** Limits the depth of the exploration of the state space. In the cartography mode, this option gives a limit to *each* call to the inverse method. Setting `-depth-limit` guarantees the termination of any execution of IMITATOR, but not necessarily the correctness of the algorithms.

`-distributed <mode>` **(default: not distributed)** Distributed version of the behavioral cartography. Various distribution modes are possible:

`no` Non-distributed mode (default)

`static` Static domain decomposition [ACN15]

`sequential` Master-worker scheme with sequential point distribution [ACE14]

`randomXX` Master-worker scheme with random point distribution (*e.g.*, `random5` or `random10`); after `XX` successive unsuccessful attempts (where the generated point is already covered), the algorithm will switch to an exhaustive sequential iteration [ACE14]

`shuffle` Master-worker scheme with shuffle point distribution [ACN15]

`dynamic` Master-worker dynamic subdomain decomposition [ACN15]

`-dynamic-elimination` **(default: false)** Dynamic elimination of clocks that are known to not used in the future of the current state [And13a].

`-fromGrML` **(default: false)** Does not use the standard input syntax described here, but a GrML input syntax. This is used when interfacing IMITATOR with the *CosyVerif* platform [AHHH$^+$13]. Note that, in that case, not all syntactic features of IMITATOR are supported.

`-IMK` **(default: false)** Uses a variant of the inverse method that returns a constraint such that no π_0-compatible state is reached; it does not guarantee however that any "good" state will be reached (see [AS13]).

`-IMunion` **(default: false)** Uses a variant of the inverse method that returns the union of the constraints associated to the last state of each path (see [AS13]).

`-incl` **(default: false)** Consider an inclusion of region instead of the equality when performing the *Post* operation. In other terms, when encountering a new state, IMITATOR checks if the same state (same location and same constraint) has been encountered before and, if so, discards this "new" state. However, when the `-incl` option is activated, it suffices that a previous state with the same location and a constraint *greater than or equal* to the constraint of the new state has been encountered to stop the analysis. This option corresponds to the way that, *e.g.*, HyTech works, and suffices when one wants to check the *non-reachability* of a given bad state.

`-merge` **(default:** `false`**)** Use the merging technique of [AFS13]. This option is safe (and advised) for the EFsynth algorithm.

However, not all the properties of the inverse method are preserved when using merging (see [AFS13] for details).

`-mode` **(default:** `inversemethod`**)** The mode for IMITATOR.

`statespace`	Generation of the entire parametric state space (see Section 4.1)
`EF`	Parametric non-reachability analysis (EFsynth [JLR15]) (see Section 4.2)
`inversemethod`	Inverse method (see Section 4.4)
`cover`	Behavioral Cartography Algorithm with full coverage (see Section 4.5)
`randomXX`	Behavioral Cartography Algorithm with `XX` iterations (see Section 4.5)

`-no-random` **(default: false)** In the inverse method, no random selection of the π_0-incompatible inequality (select the first found). By default, select an inequality in a random manner.

`-output-cart` **(default: off)** After execution of the behavioral cartography or EFsynth, plots the generated zones as a `.png` file. This will generate file `model_cart_ef.png` if the algorithm is EFsynth, `model_cart_bc.png` if the algorithm is BC and its variant, or `model_cart_patator.png` if the algorithm is the distributed BC and its variants. If the model contains more than two parameters, then `-output-cart` will plot the projection of the generated zones on the first two parameters of the model (or on the two *varying* parameters in the case of BC).

This option makes use of the external utility `graph`, which is part of the *GNU plotting utils*, available on most Linux platforms. The generated files will be located in the same directory as the source files, unless option `-output-prefix` is used.

Additional useful options are `-output-cart-x-min`, `-output-cart-x-max`, `-output-cart-y-min`, `-output-cart-y-max` to tune the values of the axes, and `-output-graphics-source` to keep the plot source.

`-output-cart-x-min` **(default: off)** Set minimum value for the x axis when plotting the cartography (not entirely functional in all situations yet).

`-output-cart-x-max` **(default: off)** Set maximum value for the x axis when plotting the cartography (not entirely functional in all situations yet).

`-output-cart-y-min` **(default: off)** Set minimum value for the y axis when plotting the cartography (not entirely functional in all situations yet).

`-output-cart-y-max` **(default: off)** Set maximum value for the y axis when plotting the cartography (not entirely functional in all situations yet).

`-output-graphics-source` **(default: false)** Keep file(s) used for generating graphical output (*e.g.*, trace set, cartography); these files are otherwise deleted after the generation of the graphics.

`-output-prefix` **(default: `<input_file>`)** Set the path prefix for all generated files. The path can be either relative (to the path to the ./imitator binary) or absolute, and must be followed by the file name.

Examples:

- `-output-prefix log`
- `-output-prefix ./log`
- `-output-prefix /home/imitator/outputs`

`-output-result` **(default: false)** Writes the result of the analysis to a file named `<input_file>.result`.

`-output-states` **(default: false)** Generates a file `<input_file>.states` describing the reachable states in plain text (value of the location, of the discrete variables, associated constraint, and its projection onto the parameters).

`-output-trace-set` **(default: false)** Graphical output using `dot`. In this case, IMITATOR outputs a file `<input_file>.jpg`, which is a graphical output in the jpg format, generated using `dot`, corresponding to the trace set.

Note that the path and the name of those two files can be changed using the `-log-prefix` option.

`-output-trace-set-nodetails` **(default: false)** In the graphical output of the trace set (see option `-output-trace-set`), does *not* provide detailed information on the local locations of the composed IPTA, and instead only outputs the state id. Enabling this option may yield a smaller graph, which is useful when generating large trace sets.

`-output-trace-set-verbose` **(default: false)** In the graphical output of the trace set (see option `-output-trace-set`), provides very detailed information, by adding to the right of the local locations of the composed IPTA the associated constraint as well. In addition, the parametric constraint is printed too. Enabling this option will yield a very large graph, and it is useful (and readable) mostly for very small trace sets.

`-PRP` **(default: false)** Option used to activate PRP or PRPC [ALNS15]. These options must be used in addition to the `-mode` option. That is, in order to call PRP, use:

```
$ ./imitator model.imi model.pi0 -PRP
```

And in order to call PRPC, use:

```
$ ./imitator model.imi model.v0 -mode cover -PRP
```

`-PTA2GrML` **(default: false)** Translates the input model to a GrML format (used by *CosyVerif* [AHHH+13]), and exits.

`-PTA2JPG` **(default: false)** Translates the input model to a graphical, human-readable form (in `.jpg` format), and exits.

`-PTA2TikZ` **(default: false)** Translates the input model to a LaTeX representation of the model (using the `tikz` package) without performing any analysis, and exits. Note that node positioning is not (much) supported, so may want to edit manually some positions.

`-states-limit` **(default: none)** Will try to stop after reaching this number of states. Warning: the program may have to first finish computing the current iteration (*i.e.*, the exploration of the state space at the current depth) before stopping.

`-statistics` **(default: false)** Print info on number of calls to PPL, and other statistics about memory and time. Warning: enabling this option may slightly slow down the analysis, and will certainly induce some extra computational time at the end.

`-step` **(default: `1`)** Step for the behavioral cartography. Integers can be used, or rationals (in the form `x/y`).

`-sync-auto-detect` **(default: false)** IMITATOR considers that all the IPTA declaring a given action must be able to synchronize all together, so that the synchronization can happen. By default, IMITATOR considers that the actions declared in an IPTA are those declared in the `synclabs` section. Therefore, if an action is declared but never used in (at least) one IPTA, this label will never be synchronized in the execution[1].

The option `-sync-auto-detect` allows to detect automatically the actions in each IPTA: the actions declared in the `synclabs` section are ignored, and IMITATOR considers as declared actions only the actions really used in this IPTA.

`-time-limit <limit>` **(default: none)** Try to limit the execution time (the value `<limit>` is given in seconds). Note that, in the current version of IMITATOR, the test of time limit is performed at the end of an iteration only (*i.e.*, at the end of the exploration of the state space at the current depth). In the cartography mode, this option represents a *global* time limit, not a limit for each call to the inverse method.

`-timed` **(default: false)** Add a timing information to each shell output of the program.

`-tree` **(default: false)** Does not test if a new state was already encountered. To be set *only* if the reachability graph is a tree with all states being different (otherwise analysis may loop).

`-verbose` **(default: `standard`)** Give some debugging information, that may also be useful to have more details on the way IMITATOR works. The admissible values for `-verbose` are given below:

`mute`	No output (the result can be output to a file using `-output-result`)
`warnings`	Prints only warnings
`standard`	Give little information (number of steps, computation time)
`low`	Give little additional information
`medium`	Give quite a lot of information
`high`	Give much information
`total`	Give really too much information

`-version` Prints IMITATOR header including the version number and exits.

[1] In such a case, action label is actually completely removed before the execution, in order to optimize the execution, and the user is warned of this removal.

Chapter 8

Grammar

8.1 Variable Names

A variable name (represented by `<name>` in the grammar below) is a string starting with a letter (small or capital), and followed by a set of letters, digits and underscores ("`_`"). By letter we mean the 26 letters of the Latin alphabet, without any diacritic mark.

The set of clock names, parameter names and discrete variable names must (quite naturally) be disjoint. However, the sets of IPTA names, location names, action names, and variable names are not required to be disjoint. That is, the same name can be given to a clock, an automaton, an action and a location.

Furthermore, the names of the sets of locations of various IPTA are not-necessarily disjoint either: that is, a same name can be given to two different locations in two different IPTA (and they still represent two different things).

8.2 Grammar of the Input File

The IMITATOR input model is described by the following grammar. Non-terminals appear ⟨*within angled parentheses*⟩. A non-terminal followed by two colons is defined by the list of immediately following non-blank lines, each of which represents a legal expansion. Input characters of terminals appear in `typewritter` font. The meta symbol ϵ denotes the empty string.

The text in green is not taken into account by IMITATOR, but allows some backward-compatibility with HyTech files [HHWT95].

⟨*imitator_input*⟩ ::
    ⟨*automata_descriptions*⟩ ⟨*init*⟩

We define each of those two components below.

8.2.1 Automata Descriptions

```
⟨automata_descriptions⟩ ::
      ⟨declarations⟩ ⟨automata⟩

⟨declarations⟩ ::
      var ⟨var_lists⟩

⟨var_lists⟩ ::
      ⟨var_list⟩ : ⟨var_type⟩ ; ⟨var_lists⟩
  |   ϵ

⟨var_list⟩ ::
      <name>
  |   <name> = ⟨rational⟩
  |   <name> , ⟨var_list⟩
  |   <name> = ⟨rational⟩ , ⟨var_list⟩

⟨var_type⟩ ::
      clock
  |   discrete
  |   parameter

⟨automata⟩ ::
      ⟨automaton⟩ ⟨automata⟩
  |   ϵ

⟨automaton⟩ ::
      automaton <name> ⟨prolog⟩ ⟨locations⟩ end

⟨prolog⟩ ::
      ⟨initialization⟩ ⟨sync_labels⟩
  |   ⟨sync_labels⟩ ⟨initialization⟩
  |   ⟨sync_labels⟩
  |   ⟨initialization⟩
  |   ϵ

⟨initialization⟩ ::
      initially <name> ⟨state_initialization⟩ ;

⟨state_initialization⟩ ::
      & ⟨convex_predicate⟩
  |   ϵ

⟨sync_labels⟩ ::
      synclabs : ⟨name_list⟩ ;
```

```
⟨name_list⟩ ::
      ⟨name_nonempty_list⟩
  |   ϵ

⟨name_nonempty_list⟩ ::
      <name> , ⟨name_nonempty_list⟩
  |   <name>

⟨locations⟩ ::
      ⟨location⟩ ⟨locations⟩
  |   ϵ

⟨locations⟩ ::
      loc <name> : while ⟨convex_predicate⟩ ⟨stop_opt⟩ ⟨wait_opt⟩ ⟨transitions⟩
  |   urgent loc <name> : while ⟨convex_predicate⟩ ⟨stop_opt⟩ ⟨wait_opt⟩ ⟨transitions⟩

⟨wait_opt⟩ ::
      wait()
  |   wait
  |   ϵ

⟨stop_opt⟩ ::
      stop{ ⟨name_list⟩ }
  |   ϵ

⟨transitions⟩ ::
      ⟨transition⟩ ⟨transitions⟩
  |   ϵ

⟨transition⟩ ::
     when ⟨convex_predicate⟩ ⟨update_synchronization⟩ goto <name> ;

⟨update_synchronization⟩ ::
      ⟨updates⟩
  |   ⟨syn_label⟩
  |   ⟨updates⟩ ⟨syn_label⟩
  |   ⟨syn_label⟩ ⟨updates⟩
  |   ϵ

⟨updates⟩ ::
     do ( ⟨update_list⟩ )

⟨update_list⟩ ::
      ⟨update_nonempty_list⟩
  |   ϵ
```

```
⟨update_nonempty_list⟩ ::
      ⟨update⟩ , ⟨update_nonempty_list⟩
  |   ⟨update⟩

⟨update⟩ ::
     <name> ' = ⟨linear_expression⟩

⟨syn_label⟩ ::
     sync <name>

⟨convex_predicate⟩ ::
      & ⟨convex_predicate_fol⟩
  |   ⟨convex_predicate_fol⟩

⟨convex_predicate_fol⟩ ::
      ⟨linear_constraint⟩ & ⟨convex_predicate⟩
  |   ⟨linear_constraint⟩

⟨linear_constraint⟩ ::
      ⟨linear_expression⟩ ⟨relop⟩ ⟨linear_expression⟩
  |   True
  |   False

⟨relop⟩ ::
      <
  |   <=
  |   =
  |   >=
  |   >

⟨linear_expression⟩ ::
      ⟨linear_term⟩
  |   ⟨linear_expression⟩ + ⟨linear_term⟩
  |   ⟨linear_expression⟩ - ⟨linear_term⟩

⟨linear_term⟩ ::
      ⟨rational⟩
  |   ⟨rational⟩ <name>
  |   ⟨rational⟩ * <name>
  |   - <name>
  |   <name>
  |   ( ⟨linear_term⟩ )

⟨rational⟩ ::
      ⟨integer⟩
      ⟨float⟩
  |   ⟨integer⟩ / ⟨pos_integer⟩
```

```
⟨integer⟩ ::
      ⟨pos_integer⟩
  |   - ⟨pos_integer⟩

⟨pos_integer⟩ ::
     <int>

⟨float⟩ ::
      ⟨pos_float⟩
  |   - ⟨pos_float⟩

⟨pos_float⟩ ::
     <float>
```

8.2.2 Initial State

```
⟨init⟩ ::
     ⟨init_declaration⟩ ⟨init_definition⟩ ⟨property_definition⟩ ⟨projection_definition⟩ ⟨other_commands⟩

⟨init_declaration⟩ ::
      var init : region ;
  |   ϵ

⟨other_commands⟩ ::
      end ⟨rest_of_commands⟩
  |   ϵ

⟨rest_of_commands⟩ ::
      ⟨anything⟩ ⟨rest_of_commands⟩
  |   ϵ

⟨anything⟩ ::
      (
  |   )
  |   <name>
  |   init
  |   bad

⟨init_definition⟩ ::
     init := ⟨region_expression⟩ ;

⟨region_expression⟩ ::
      & ⟨region_expression_fol⟩
  |   ⟨region_expression_fol⟩
```

```
⟨region_expression_fol⟩ ::
      ⟨state_predicate⟩
  |   ( ⟨region_expression_fol⟩ )
  |   ⟨region_expression_fol⟩ & ⟨region_expression_fol⟩

⟨state_predicate⟩ ::
      loc [ <name> ] = <name>
  |   ⟨linear_constraint⟩

⟨loc_predicate⟩ ::
      loc[ <name> ]  =  <name>

⟨property_definition⟩ ::
      property  := ⟨pattern⟩ ;
  |   ϵ

⟨pattern⟩ ::
      unreachable ⟨loc_predicate⟩
  |   if <name> then <name> has happened before
  |   everytime <name> then <name> has happened before
  |   everytime <name> then <name> has happened once before
  |   if <name> then eventually <name>
  |   everytime <name> then eventually <name>
  |   everytime <name> then eventually <name> once before next
  |   <name> within ⟨linear_expression⟩
  |   if <name> then <name> happened within ⟨linear_expression⟩ before
  |   everytime <name> then <name> happened within ⟨linear_expression⟩ before
  |   everytime <name> then <name> happened once within ⟨linear_expression⟩ before
  |   if <name> then eventually <name> within ⟨linear_expression⟩
  |   everytime <name> then eventually <name> within ⟨linear_expression⟩
  |   everytime <name> then eventually <name> within ⟨linear_expression⟩ once before next
  |   sequence ⟨var_list⟩
  |   sequence always ⟨var_list⟩
```

8.3 Grammar of the Reference Valuation File

The reference valuation file (usually named `model.pi0`) gives a constant value to any parameter of the model; this file is used for IM and PRP.

It basically consists of a sequence of equalities `parameter = constant` separated (or not!) by the `&` symbol. All parameters of the model must be given a valuation in this file; but the file may also use names that do not appear in the model (a warning will just be issued).

Arithmetic expressions (using integers and rationals) can even be used instead of just constants.

8.4 Grammar of the Reference Hyperrectangle File

The hyperrectangle file (usually named `model.v0`) defines a bounded parameter domain, *i.e.*, a hyperrectangle having as dimensions the parameters of the model; this file is used for BC and PRPC.

It basically consists of a sequence of either equalities `parameter = constant` or intervals `parameter = constant .. constant` separated (or not!) by the `&` symbol. All parameters of the model must be given an interval (possibly punctual) in this file; again, the file may also use names that do not appear in the model (a warning will just be issued).

Again, arithmetic expressions (using integers and rationals) can even be used instead of just constants.

8.5 Reserved Words

The following words are reserved keywords and cannot be used as names for automata, variables, actions or locations.

`always`, `and`, `automaton`, `bad`, `before`, `carto`, `clock`, `constant`, `discrete`, `do`, `end`, `eventually`, `everytime`, `False`, `goto`, `happened`, `has`, `if`, `init`, `initially`, `loc`, `locations`, `next`, `not`, `once`, `or`, `parameter`, `projectresult`, `property`, `region`, `sequence`, `stop`, `sync`, `synclabs`, `then`, `True`, `unreachable`, `urgent`, `var`, `wait`, `when`, `while`, `within`

Chapter 9

Missing Features

Although we try to make IMITATOR as complete as possible, it misses some features, not implemented due to lack of time (contributors are welcome!) or due to complexity, or to keep the tool consistent. We enumerate in the following what seems to us to be the "most missing" features and, when applicable, we give hints to overcome these limitations.

9.1 ASAP Transitions

ASAP (as soon as possible) transitions are transitions that can be taken as soon as all IPTA synchronizing with this transition can execute their local transition. This is different from urgent transitions, that must be taken in 0 time. Here, time can elapse, but not after all IPTA are ready to execute their local transition.

This is not supported by IMITATOR, and we do not see a way to simulate it easily in the current implementation.

9.2 Parameterized Models

Parameterized models are understood here as models with an arbitrary number of components (*e.g.*, Fischer's mutual exclusion protocol with n processes), that would be instantiated (*e.g.*, $n = 15$) before performing the analysis. IMITATOR does not currently support such parameterized models, and one should use copy/paste utilities to instantiate n models. For complicated models with many processes, we usually write short scripts to generate the model (a script `CSMACDgenerator.py` to model the varying part of parameterized models for the CSMA/CD case study is available on GitHub).

9.3 Other Synchronization Models

One-to-one synchronization could possibly be simulated by using as many transitions as pairs of IPTA in the model, although this may make the model rather complex.

Broadcast synchronization ("only the IPTA ready to execute a given transition execute it") is not supported. Once more, it could possibly be simulated by using as many transitions as subsets of IPTA in the model, although this will make the model definitely complex.

Message passing is not supported. This can be easily simulated using dedicated discrete variables, that would be read / written in the transition.

9.4 Intervals for Discrete Variables

Discrete variables must be set to a constant integer in the `init` definition (*e.g.*, `i = 0`). Setting a variable to an arbitrarily value (*e.g.*, `i in [0 .. 10]`) is currently not supported. This can be simulated using an initialization IPTA that nondeterministically sets `i` to any of the values, in 0 time so as to not disturb the model.

9.5 Complex Updates for Discrete Variables

So far, discrete variables can only be set to linear terms in $\mathscr{LT}(\mathrm{D})$; hence, assigning a discrete variable to a clock, or to a parameter, or to any more complex expression, is not allowed. A reason for this restriction is that the value of the discrete variables would not anymore be constant (recall that discrete variables are syntactic sugar for *locations*).

However, this can be (partially) simulated with stopwatches: we can replace a discrete variable with a clock that is stopped in all locations (*i.e.*, it does not evolve with time), and that is updated to the desired value (recall from Definition 1 that the clock updates are more permissive than the discrete variable updates).

Chapter 10

Acknowledgments

Étienne André initiated the development of IMITATOR in 2008, and keeps developing it. Emmanuelle Encrenaz and Laurent Fribourg have been great supporters of IMITATOR, on a theoretical point of view, and to find applications both from the literature and real case studies. Abdelrezzak Bara provided several examples from the hardware literature. Jeremy Sproston provided examples from the probabilistic community. Bertrand Jeannet has been of great help on the linking with Apron [JM09] in a previous version of IMITATOR. Ulrich Kühne made several important improvements to IMITATOR, and linked the tool to PPL. Daphne Dussaud implemented the graphical output of the behavioral cartography. Romain Soulat implemented in part the merging technique [AFS13], and brought several case studies. Giuseppe Lipari and Sun Youcheng provided examples from the real-time systems community, and collaborated on several algorithms. Camille Coti, Sami Evangelista and Nguyen Hoang Gia worked on the distributed version of IMITATOR.

Chapter 11

Licensing and Credits

IMITATOR license

IMITATOR is available under the GNU GPL license.

Contributors

The following people contributed to the development of IMITATOR.

Étienne André	2008 –
Camille Coti	2014 –
Daphne Dussaud	2010
Sami Evangelista	2014
Ulrich Kühne	2010 – 2011
Nguyen Hoang Gia	2014 –
Romain Soulat	2010 – 2013

The following people contributed to the compiling and packaging facilities.

Corentin Guillevic	2015
Sarah Hadbi	2015
Fabrice Kordon	2015 –
Alban Linard	2014 –

User Manual

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